Calibration of visual angle car following model based on real site traffic data

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Abstract:
Traffic simulation models have increasingly been used due to low cost, time saving and ability to examine possible solutions for traffic-related problems without interrupting the real life traffic conditions during testing alternative scenarios. Recently, visual angle car following model has been studied and examined by the author for use in developing a micro-simulation car following model. The proposed model has been tested for different angular velocity thresholds against real published traffic data by developing a simple-one lane micro-simulation program. The results show that when the suggested angular velocity threshold of about 0.003 rad/sec is applied, the model will become able to replicate real life traffic movements. Root Mean Square and Error Metric statistical tests have been used to compare different selected angular velocity thresholds. A non parametric, Kolmogorov-Smirnov test indicates that the difference between the observed and simulated data is significant when the angular velocity threshold is below a value of 0.002 rad/sec. The aim of developing this car following model is to be used at a later stage in developing a micro-simulation model to represent traffic behaviour at motorway merges and to test the objectiveness of using ramp metering strategies on motorways.

Keywords:
Car following, visual angle, micro-simulation, car following calibration

1 Introduction

Traffic simulation models play a major role in allowing transportation engineers to evaluate complex traffic situations and recommending alternative scenarios. Such simulation models provide the opportunity to evaluate traffic control and design strategies without committing a lot of expensive resources (including time) which are necessary to implement alternative strategies in the field (Clark and Daigle, 1997). According to Kotsialos and Papageorgiou (2001) these models can be used for estimation, prediction and control related tasks for the traffic process. Moreover, computer simulation models can help in analysing every day's traffic management needs by looking at problems such as congestion and identify their sources.

The main components of any traffic simulation model are car following, lane changing and gap acceptance models. Car-following models describe the relationship between pairs of vehicles in a single lane. This relationship is represented by several mathematical models which basically describe the effect of the leading vehicle on its follower. The lane changing model represents the lateral movement for traffic movements. The feasibility of making a

decision for lane changing is based on the availability of sufficient gap in a target lane. Usually, the availability of such gap is controlled by gap acceptance model.

Car following models are well described and classified in the literature (see for example, Brackstone and McDonald (1999) and Panwai and Dia (2005)). This paper will focus on calibration of the visual angle car following model proposed by Al-Obaedi and Yousif (2009a, b).

2 Visual angle car following models

One of the earlier car-following models is the visual angle model. The visual angle as shown in Figure 1 is given by the following equation:

$$\theta = 2\tan^{-1}\left(\frac{w}{2H}\right) \qquad \text{.... Equation 1}$$

Where:

w is a width of the leading vehicle.
H is the spacing between the leading and the following vehicles.

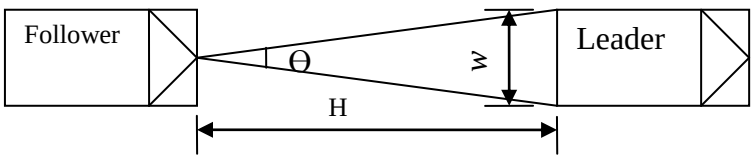

Figure 1 Illustration of the visual angle (Θ)

Michaels (1963) observed that the detection of the relative velocity depends on the rate of change of angular motion (angular velocity) of an image across the retina of the eye of the follower driver (Fox and Lehman, 1967).
The angular velocity is found by differentiating Equation 2 with respect to the time (t)

$$\frac{\Delta\theta}{\Delta t} = -w\frac{V_L - V_F}{(X_L - length(l) - X_F)^2} \qquad \text{.... Equation 2}$$

Where:

V_L and V_F are speeds of leading and following vehicles, respectively.
w is the width of leading vehicle.
X_L and X_F are positions of leading and following vehicles, respectively.
length(l) is the length of the leading vehicle.

Visual angle models are described by previous researchers, such as Brackstone and McDonald (1999), and Panwai and Dia (2005), as one type of psychophysical or action point models since these models define the next vehicle's action on whether or not the follower exceeds certain thresholds. These assume fixed values (thresholds) for angular velocity. Once the absolute value of the angular velocity exceeds the threshold, the follower will accelerate or decelerate opposite to the sign of the relative angular velocity. Table 1 presents a brief summary of the values used for angular velocity thresholds by various researchers.

Recently, theoretical studies carried out by Al-Obaedi and Yousif (2009a, b) have argued that higher values for the angular velocity thresholds such as a value of 0.003 rad/sec as proposed by Hoffman and Mortimer (1994, 1996) are more reasonable. However, no real traffic data have been used in these studies. This paper tries to fill the gap in these studies through examining different angular velocity thresholds using published real site traffic data.

Table 1 Summary of angular velocity thresholds used by various researchers

Researcher(s)	Threshold value ($\Delta\Theta/\Delta t$) (rad/sec)	Remarks
Michaels and Cozan (1963)	0.0003 – 0.001	Experimental
Fox and Lehman (1967)	0.0006	Simulation
Ferrari (1989)	0.0003	Simulation
Hoffman and Mortimer (1994 and 1996)	0.003	Experimental
Xin et al. (2008)	0.0008	Simulation

3 Visual angle model thresholds and assumptions

This section presents thresholds and assumptions for the visual angle model which are used in this study as described by Al-Obaedi and Yousif (2009a, b).

Four thresholds are used in the proposed model. Positive and negative angular velocity thresholds are used to arrange the difference in speed between the leader and the follower. While minimum and maximum time spacing thresholds (MinTH and MaxTH) are used to represent driver error in estimating his/her headway according to Weber's law (Brackstone, and McDonald, 1999)

The main assumption of the model is based on whether or not the angular velocity calculated from Equation 2 exceeds the assumed angular velocity threshold values. If the absolute angular velocity becomes higher than a certain selected threshold, the follower starts to accelerate or decelerate opposite in sign to that of the angular velocity value.

If the MaxTH threshold is exceeded, the follower will start applying acceleration to reach his/her desired headway. On the other side, if the MinTH is exceeded, the follower will apply deceleration in order to recover his/her desired headway.

If the angular velocity value calculated from Equation 2 is within the two visual angle threshold limits, and if the minimum and maximum time headway thresholds are not exceeded, the driver is assumed to keep a constant speed.

The selected values for acceleration or deceleration are the minimum of the following rates (see for example Fox and Lehman, 1967 and Ferrari, 1989):

- the acceleration rate which is required to reach the desired speed,
- the acceleration/deceleration rate required to reach the leader's speed, and
- the acceleration/deceleration rate required to maintain the desired spacing using the following Equation 3 below. This equation is derived based on the same assumptions reported by Hidas (1996).

$$ac(f) = \frac{x(l,t+\Delta t) - x(f,t) - v(f,t)*\Delta t - DTHead(f)*v(f,t) - length(l) - Buf}{\frac{\Delta t^2}{2} + DTHead(f)*\Delta t}$$

…Equation 3

Where:

$ac(f)$ is the acceleration (or deceleration) rate of the follower

Δt is the scanning time.

$DTHead(f)$ is the desired time (spacing) for the follower.
$x(l, t+\Delta t)$ is the position of the leader at time $t+\Delta t$
(other terms are as defined before).
Buf is the required buffer spacing by the follower.
$v(f,t), x(f,t)$ are speed and position of the follower at time *t, respectively.*

4 Calibration Methodology

The reliability of any model depends on how well that model could represent the reality (Barceló and Casas, 2002). The calibration of simulation models is an iterative process to select the best parameters for a given model depends on real traffic data.

For this paper, real traffic data as reported by Panwai and Dia (2005) has been used to calibrate the visual angle model. The model parameters will be varied to find out the best fit for the data based on statistical tests. The following subsections explain the data, statistical tests that used, and the calibration parameters. A micro-simulation program has been prepared as a bed test for this study.

4-1 Data description

The source of the data used in this paper is taken from Panwai and Dia (2005) which is based on two vehicles trajectories while these vehicles are travelling at stop-and-go conditions for a distance of 2.5 km for 300 seconds. Figure 2 shows the speed profile for the leading vehicle while Figures 3 and 4 represent the clear spacing and relative speed profile between these two vehicles respectively. The speed range was between 0 and 60 km/hr. As shown in Figure 2, both vehicles came to full stop several times during the whole period. For the purpose of this research, numerical values for the leading speed from Figure 2 and the clear spacing from figure 3 are abstracted for each 0.5 seconds interval.

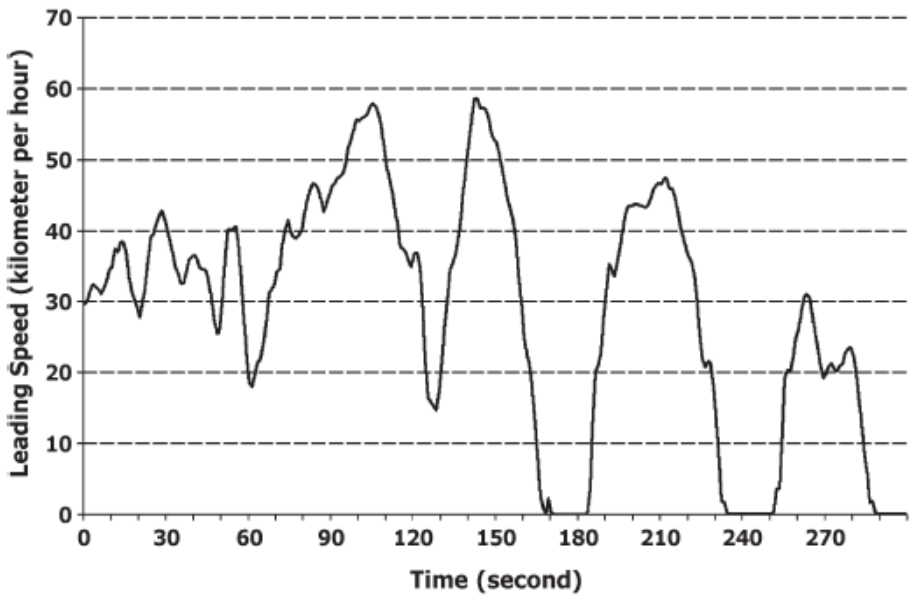

Figure 2 Leading vehicle profile (source: Panwai and Dia, 2005)

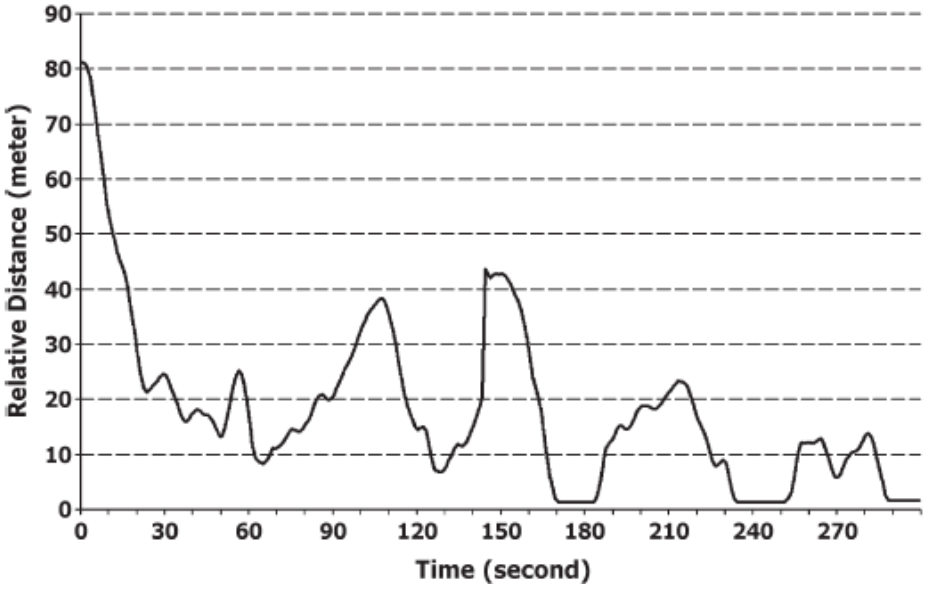

Figure 3 Clear spacing between the two vehicles (source: Panwai and Dia, 2005)

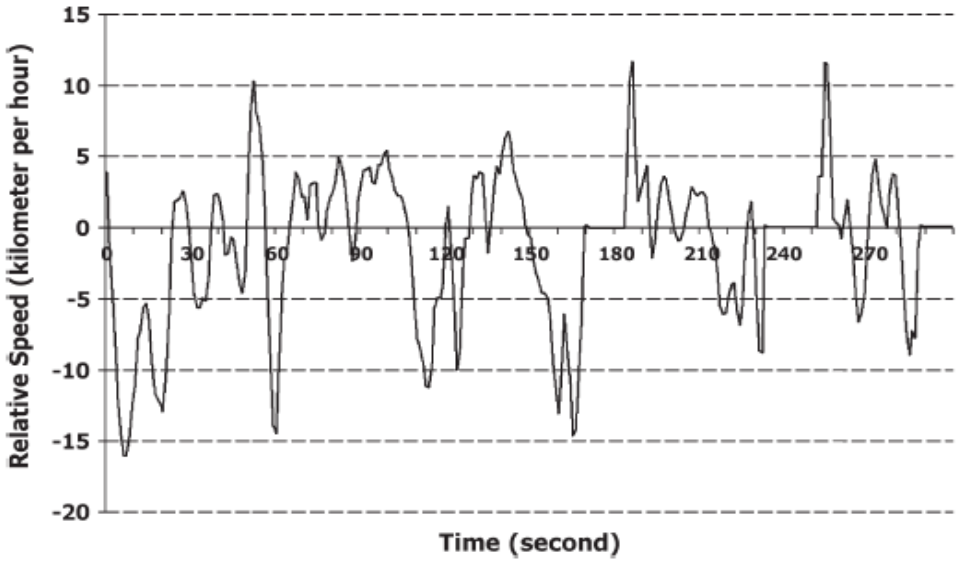

Figure 4 Relative speed profiles between the two vehicles (source: Panwai and Dia, 2005)

According to Panwai and Dia (2005) this data has been used to evaluate the behaviour of different micro-simulation models. Table 2 shows a summary of some of the work done using this.

Table 2 Summary of car following models which were evaluated using the data

Model	Statistical tests		Reference
	Root mean square error	Error metric	
MITSIM	Not used	3.75	Manstetten et al. (1997)
Wied/Pel	Not used	14.01	Manstetten et al. (1997)
Wied/VIS	Not used	10.67	Manstetten et al. (1997)
NSM	Not used	24.51	Manstetten et al. (1997)
OVM	Not used	9.37	Manstetten et al. (1997)
T^3M	Not used	2.4	Manstetten et al. (1997)
AIMSUN (v4.15)	4.99	2.55	Panwai and Dia (2005)
VISSIM (v3.70)	5.05	4.78	Panwai and Dia (2005
PARAMICS (v4.1)	10.43	4.68	Panwai and Dia (2005

4-2 Statistical tests

Root mean square error (RMSE) and Error metric (EM) statistical tests (see Equations 4&5) have been used in this study to estimate the error value for the actual and simulated clear spacing between the two vehicles. Moreover, Kolmogorov-Smirnov non parametric test has been used to make a decision on whether to accept or reject the hypothesis that observed and simulated data (in term of clear spacing) are significantly different.

$$RMSE = \sqrt{\frac{(ds - df)^2}{n}} \qquad \text{…Equation 4}$$

$$EM = \sqrt{\left(\log\frac{ds}{df}\right)^2} \qquad \text{…Equation 5}$$

Where:

ds is the simulated spacing between two vehicles (m)
df is the actual spacing between two vehicles (m)

4-3 Model parameters

Some of the model parameters could be directly estimated form the data. These include the desired speed and the buffer spacing for the follower. The desired spacing of 60 km/hr has been assigned for the follower representing the maximum follower's speed during the period of 300 seconds. For the buffer spacing, a value of 1.5 m has been chosen representing the minimum spacing between the two vehicles at stopping conditions.

The desired time headway DTHead given in Equation 3 is chosen as 1.6 sec. based on several iterations to select this parameter. The selected parameters for calibration are the absolute angular velocity threshold Θ, minimum (MinTH) and maximum (MaxTH) time spacing. Angular velocity thresholds values from 0.0001 to 0.006 rad/sec are used. Values of (1.12*DTHhead, 1.2*DTHhead) and (0.88*DTHhead, 0.8*DTHhead) are selected for each minimum and maximum time headway thresholds, respectively to represent the effect of just noticeable difference according to Weber law (Brackstone and McDonald, 1999). Table 3 represents the combination of these parameters used in the calibration process.

Table 3 Combinations of the calibration parameters

Case	Selected Θ values (rad/sec)	MinTH (sec)	MaxTH (sec)
A	0.0001, 0.0003, 0.0008, 0.001, 0.002, 0.003, 0.004, 0.005 and 0.006	0.88*DTHead	1.12*DTHead
B		0.8*DTHead	1.2*DTHead

5 Results and discussion

Figures 5 and 6 represent the actual and simulation spacing between the two vehicles for Cases A and B with angular velocity threshold of 0.003 rad/sec. Although both figures show good agreement between simulated and observed spacings depending on RMSE values, the EM values as shown are too high compared with values in Table 2. Not like RMSE, the EM depends on the ratio of simulated to observed values as shown in Equation 5 and therefore, the higher values of EM for the cases in Figures 5 and 6 are due to stopping conditions (see circled parts in Figures 5 and 6) . Therefore, further modification is required to the visual angle model assumptions relating to stopping conditions.

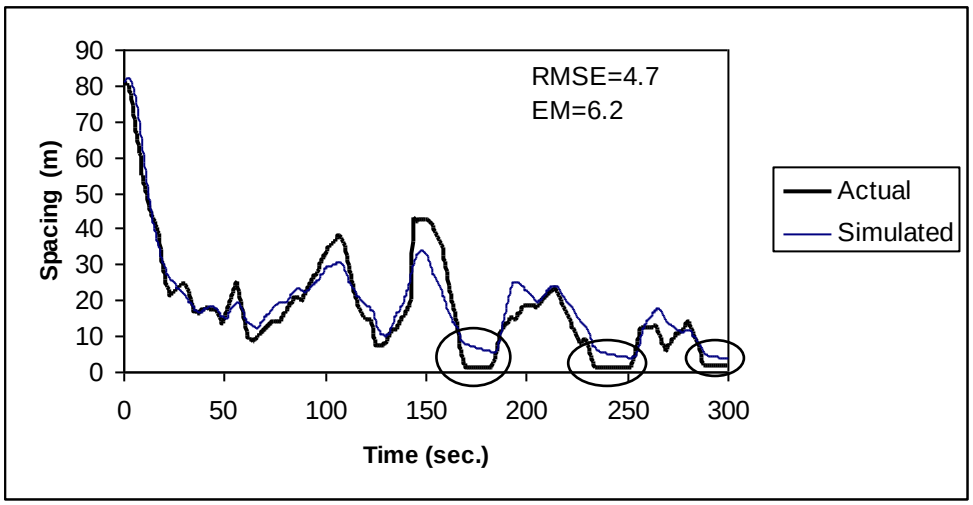

Figure 5 Actual and simulated spacing for case A with Θ of 0.003 rad/sec

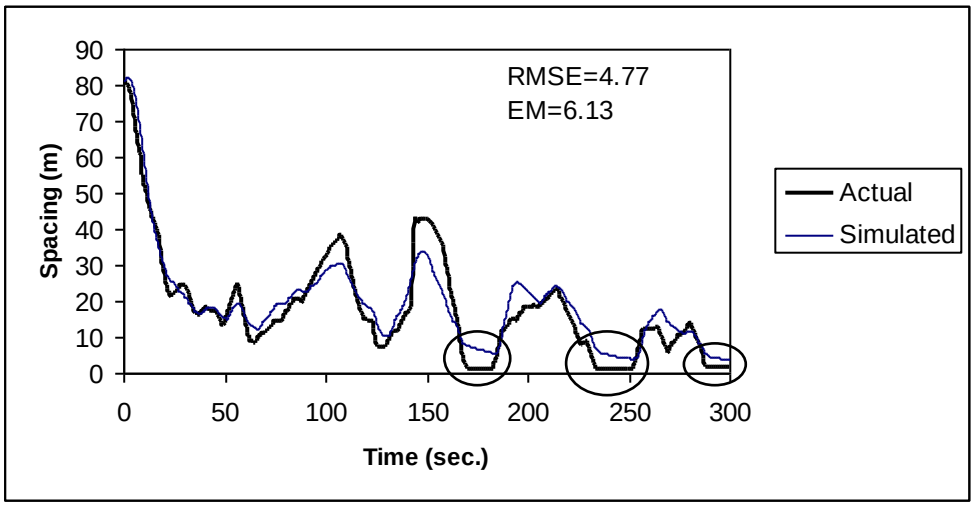

Figure 6 Actual and simulated spacing for case B with Θ of 0.003 rad/sec

The suggested modification states that at slow speeds (up to 25 km/hr based on sensitivity analyses for this factor), drivers will not tend to react to the difference in speed and the main goal at this range of speed is to keep a minimum buffer distance. In the model and when the speed is less than 25 km/hr, the acceleration of the follower is assumed to be the minimum acceleration to maintain the desired speed or to reach the desired headway from Equation 3. The effect of this new assumption on the results for the same angular velocity threshold value of 0.003 rad/sec is shown in Figures 7&8 where both RMSE and EM seem to be within acceptable values. Moreover, the RMSE is found to be less than those in Table 2 which indicate that the visual angle model is able to replicate real traffic movements and therefore, the rest of work in this paper will be based on this assumption.

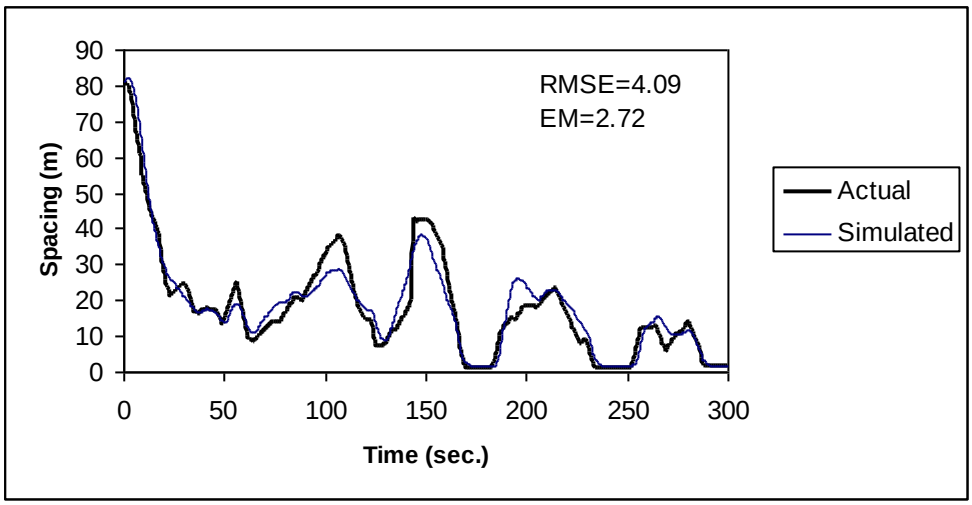

Figure 7 Actual and simulated spacing for case A with Θ of 0.003 rad/sec

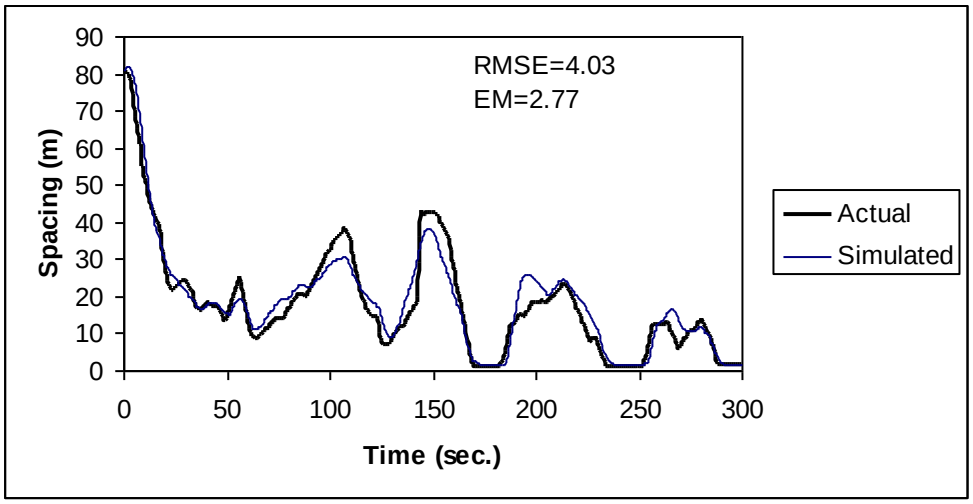

Figure 8 Actual and simulated spacing for case B with Θ of 0.003 rad/sec

Also, there is no significant difference between Cases A and B. Therefore, it is decided to test other values of the angular velocity threshold depending on case A only. Figures 9-15 represent the actual and simulated spacing for different angular velocity thresholds for Case A only.

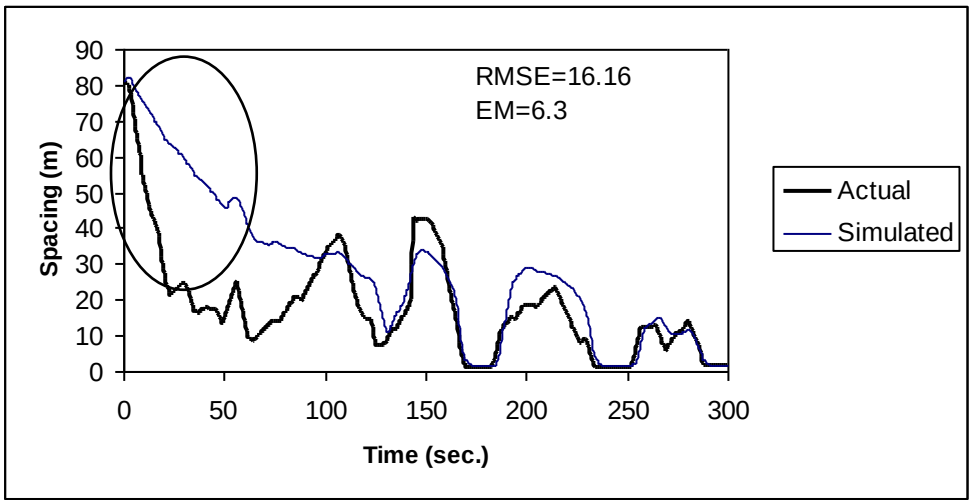

Figure 9 Actual and simulated spacing for case B with Θ of 0.0003 rad/sec

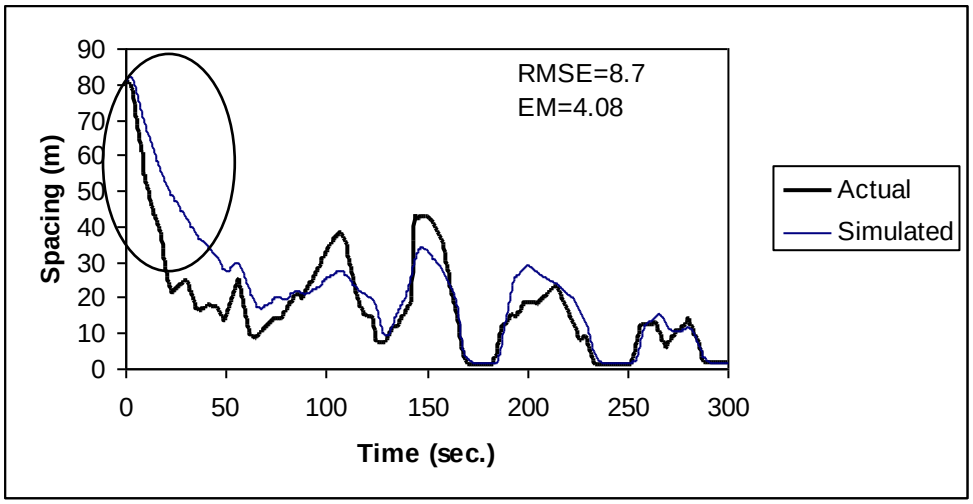

Figure 10 Actual and simulated spacing for case B with Θ of 0.0008 rad/sec

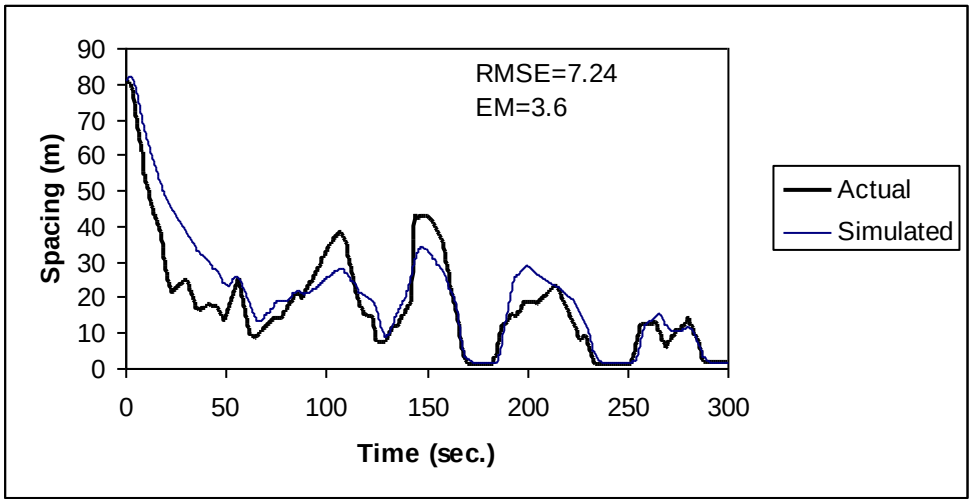

Figure 11 Actual and simulated spacing for case B with Θ of 0.001 rad/sec

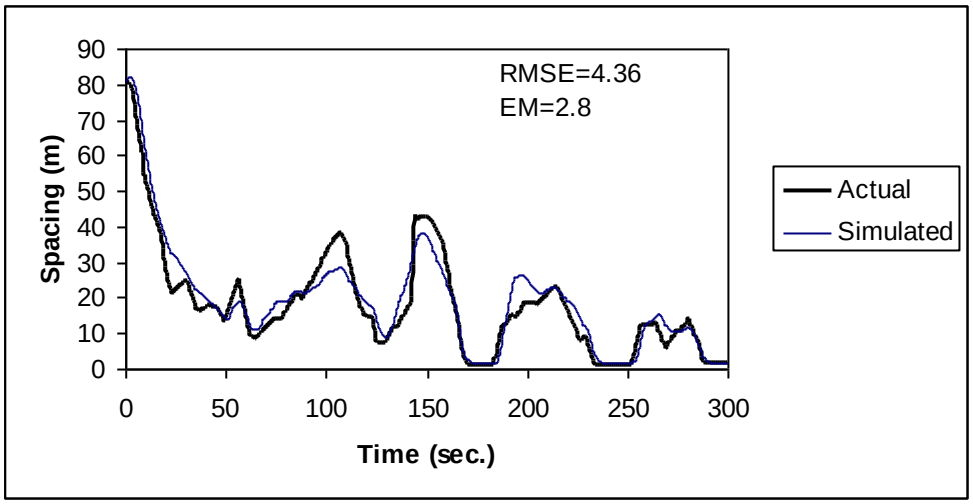

Figure 12 Actual and simulated spacing for case B with Θ of 0.002 rad/sec

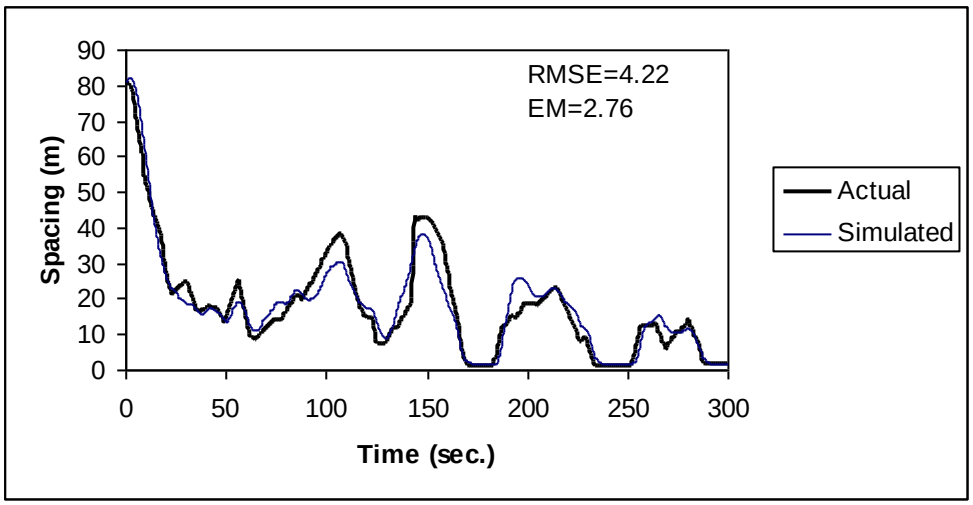

Figure 13 Actual and simulated spacing for case B with Θ of 0.004 rad/sec

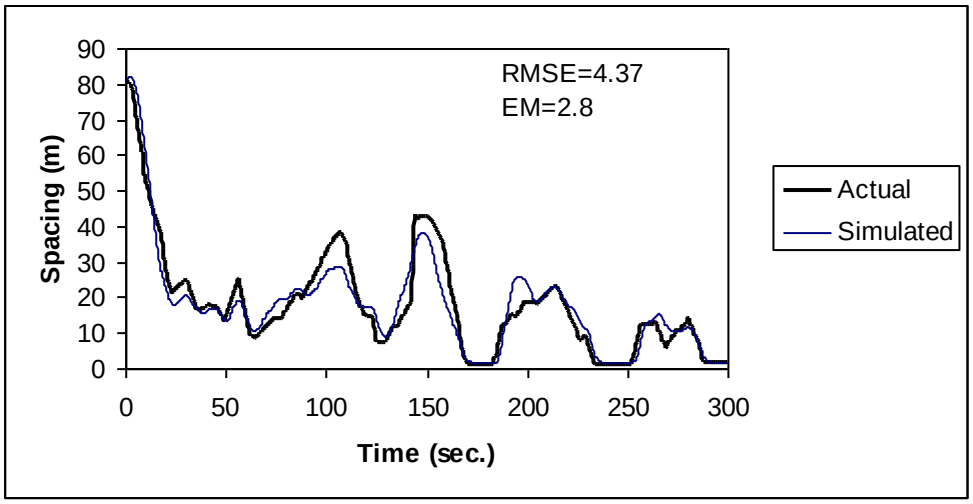

Figure 14 Actual and simulated spacing for case B with Θ of 0.005 rad/sec

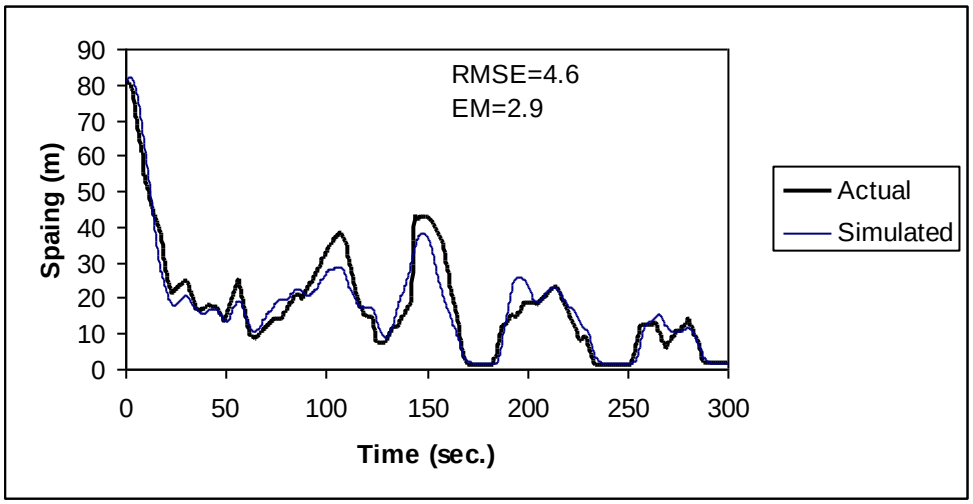

Figure 15 Actual and simulated spacing for case B with Θ of 0.006 rad/sec

The figures show that only when the angular velocity is 0.002 rad/sec or higher, there will be good agreement between the real data and the model. As shown in Figures 7 and 8, the minimum values for RMSE are 4.09 for Case A and 4.03 for Case B with angular velocity

threshold of 0.003 rad/sec. Compared with other car following models, these values (i.e.4.03 and 4.09) are found to be lower than all values reported in Table 2.

The problem in applying lower values of angular velocity thresholds such as a value of 0.0003 rad/sec as used by Fox and Lehman (1967) and Ferrari (1989) or a value of 0.0008 rad/sec as used by Xin et al. (2008) is that the follower will apply deceleration rate even when the distance between the two vehicles is too high. This behaviour is shown in the circled part of Figures 9 and 10 for the angular velocity threshold of 0.0003 rad/sec and 0.0008 rad/sec respectively.

6 Hypothesis testing

In order to find whether or not the difference between the simulated and real spacings is significant, Kolmogorov-Smirnov test has been used. According to this non parametric test, a hypothesis is accepted (i.e. the difference is insignificant) if the maximum difference (Dmax) in the cumulative probability is less than the critical limit (Dcr). If the difference is higher than that limit, a hypothesis is rejected (i.e. the difference is significant). Table 4 represents a summary of applying this test for the 95% confidence level.

Table 4 Hypothesis testing summary

Angular velocity threshold	RMSE	EM	G-S test		Hypotheses
			Dcr	Dmax	
0.0003	16.16	6.3	0.055	0.133	Rejected
0.0008	8.7	4.08	0.055	0.085	Rejected
0.001	7.24	3.60	0.055	0.063	Rejected
0.002	4.36	2.80	0.055	0.028	Accepted
0.003	4.09	2.72	0.055	0.034	Accepted
0.004	4.22	2.76	0.055	0.035	Accepted
0.005	4.37	2.80	0.055	0.036	Accepted
0.006	4.6	2.9	0.055	0.037	Accepted

The Table shows that the hypothesis is only accepted when the angular velocity threshold is about 0.002 rad/sec or higher. This confirms the theoretical work by Al-Obaedi & Yousif (2009a, b) in suggesting the use of higher values for the angular velocity thresholds in visual angle car following models.

7 Conclusion and Further Research

Visual angle car following model has been calibrated using real site data based on two vehicles trajectories as reported by Panwai and Dia (2005). The main finding of this study is confirming previous theoretical work by Al-Obaedi & Yousif (2009a, b) in suggesting the use of higher values for the angular velocity thresholds in car following models than used in the past in simulation applications.

It was found that using of angular velocity threshold of 0.002 rad/sec. and higher gives good replication of the real data. Moreover, the RMSE from the visual angle model is less than that reported in previous research work for other car following models using the same data.

Further research is needed to examine the ability of the visual angle car following model to replicate real traffic movements according to types of vehicles (i.e. Car Following Car, Car following HGV, HGV following HGV and HGV following Car).

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